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Description

VEHICLE AND METHOD FOR CONTROLLING ENGINE START IN A VEHICLE

BACKGROUND OF INVENTION

[0001] 1. Field of the Invention

[0002] The present invention relates to a vehicle and a method for controlling engine start in a vehicle.

[0003] 2. Background Art

[0004] With the increasing concern for reducing vehicle emissions, hybrid electric vehicles (HEV's) are becoming increasingly popular. One way that an HEV provides reduced emissions, is by shutting off the engine and operating the vehicle with one or more electric motors. The engine is usually shut off during times when vehicle torque requirements are not high. If, for example, the driver demands a torque increase beyond a certain point, the engine may need to be restarted to augment the torque produced by

the motor. Thus, while the vehicle is operating, the engine may be started and stopped many times, depending on the operating conditions.

[0005] In addition to providing torque for the vehicle wheels, an electric motor in an HEV can be used to start the engine. The motor, which receives power from an electrical storage device, such as a battery, spins the engine until a predetermined speed is reached, whereat fuel is provided to the engine, and the engine begins to produce torque. Because the engine may be stopped and started many times while the vehicle is operating, the engine start should be transparent to the driver. Therefore, the engine should be started such that the amount of torque delivered to the wheels will not be reduced because the state of charge (SOC) of the battery is too low. If the SOC is allowed to drop below a certain point, the amount of torque provided to the vehicle wheels by the motor may need to be reduced in order to provide enough torque to start the engine. This would create a non-transparent engine start, and degrade drivability.

[0006] One attempt to deal with this issue is discussed in U.S. Patent No. 6,424,157 issued to Gollomp et al. on July 23, 2002. Gollomp et al. describes a system and method for

monitoring a vehicle battery, including a battery used in an HEV. In the Gollomp et al. system, a computer is pre-programmed with battery performance data taken from external sources. Ambient temperature data is then collected, and maximum current use data for starting current versus measured ambient temperature is calculated. A message can then be provided to a vehicle operator to indicate the amount of time remaining before the battery will not have enough power to start the engine. If the time remaining is less than some predetermined amount of time, the message may appear in the form of a warning.

[0007] One limitation of the Gollomp et al. system is that it only provides an indicator of when the battery can no longer start the engine; it does not provide an indicator of when starting the engine will reduce the torque provided to the vehicle wheels. The point at which torque to the vehicle wheels must be reduced may come well before the point at which the battery can no longer provide enough power to start the engine. Therefore, the Gollomp et al. system does not ensure a transparent engine start.

SUMMARY OF INVENTION

[0008] One advantage of the present invention is that it provides a vehicle and method for controlling engine start in a ve-

hicle that helps to ensure a transparent engine start that does not degrade drivability.

[0009] The invention also provides a method for controlling engine start in a vehicle. The vehicle includes an electric machine operable to provide a starting torque to the engine, and an energy storage device capable of providing energy to operate the electric machine. The method includes determining a discharge power limit for the energy storage device. An output power, and an engine starting power level, for the energy storage device is determined. The engine starting power level is related to the discharge power limit for the energy storage device and an amount of power for the energy storage device necessary to operate the electric machine to provide the starting torque to the engine. The engine is started when the output power of the energy storage device is at or above the engine starting power level.

[0010] The invention further provides a method for controlling engine start in a vehicle. The engine includes an electric machine operable to provide a starting torque to the engine, and an energy storage device capable of providing energy to operate the electric machine. The method includes monitoring an output power of the energy storage

device. A first output power level for the energy storage device is determined, based at least in part on an amount of output power required by the electric machine to provide the starting torque for the engine. The engine is started when the output power of the energy storage device meets or exceeds the first output power level.

[0011] The invention also provides a vehicle, including an engine, an electric machine operable to drive the vehicle and to provide a starting torque to the engine, and an energy storage device capable of providing energy to operate the electric machine. The vehicle also includes at least one controller configured to determine a discharge power limit for the energy storage device and an output power of the energy storage device. The at least one controller is further configured to determine an engine starting power level for the energy storage device and start the engine when the output power of the energy storage device is at or above the engine starting power level. The engine starting power level is related to the discharge power limit for the energy storage device and an amount of power of the energy storage device necessary to operate the electric machine to provide the starting torque to the engine.

Brief Description of Drawings

[0012] Figure 1 is a schematic representation of a vehicle in accordance with the present invention;

[0013] Figure 2 is a graph illustrating the relationship between battery output power, engine starting power level, and discharge power limit;

[0014] Figure 3 is a flowchart illustrating a method in accordance with the present invention;

[0015] Figure 4 is a graph illustrating how an amount of battery output power required to start an engine can be determined; and

[0016] Figure 5 is a schematic representation of a function that can be used to determine the engine starting power level.

DETAILED DESCRIPTION

[0017] Figure 1 shows a schematic representation of a vehicle 10 in accordance with the present invention. The vehicle 10 includes an engine 12 and an electric machine, or generator 14. The engine 12 and the generator 14 are connected through a power transfer unit, which in this embodiment is a planetary gear set 16. Of course, other types of power transfer units, including other gear sets and transmissions may be used to connect the engine 12 to the generator 14. The planetary gear set includes a ring gear 18, a carrier 20, planet gears 22, and a sun gear 24.

[0018] The generator 14 can also be used as a motor, outputting torque to a shaft 26 connected to the sun gear 24. Similarly, the engine 12 outputs torque to a shaft 28 connected to the carrier 20. A brake 30 is provided for stopping rotation of the shaft 26, thereby locking the sun gear 24 in place. Because this configuration allows torque to be transferred from the generator 14 to the engine 12, a one-way clutch 32 is provided so that the shaft 28 rotates in only one direction. Having the generator 14 operatively connected to the engine 12, as shown in Figure 1, allows the speed of the engine 12 to be controlled by the generator 14.

[0019] The ring gear 18 is connected to a shaft 34, which is connected to vehicle drive wheels 36 through a second gear set 38. The vehicle 10 includes a second electric machine, or motor 40, which can be used to output torque to a shaft 42. Other vehicles within the scope of the present invention may have different electric machine arrangements, such as more or less than two electric machines. In the embodiment shown in Figure 1, the motor 40 and the generator 14 can both be used as motors to output torque. Alternatively, each can also be used as a generator, outputting electrical power to a high voltage bus 44

and to an energy storage device, or battery 46.

[0020] The battery 46 is a high voltage battery that is capable of outputting electrical power to operate the motor 40 and the generator 14. Other types of energy storage devices and/or output devices can be used with a vehicle, such as the vehicle 10. For example, a device such as a capacitor can be used, which, like a high voltage battery, is capable of both storing and outputting electrical energy. Alternatively, a device such as a fuel cell may be used in conjunction with a battery and/or capacitor to provide electrical power for the vehicle 10.

[0021] As shown in Figure 1, the motor 40, the generator 14, the planetary gear set 16, and a portion of the second gear set 38 may generally be referred to as a transaxle 48. To control the engine 12 and the components of the transaxle 48--i.e., the generator 14 and motor 40--a controller 50 is provided. As shown in Figure 1, the controller 50 is a vehicle system controller (VSC), and although it is shown as a single controller, it may include multiple controllers. For example, the VSC 50 may include a separate powertrain control module (PCM), which could be software embedded within the VSC 50, or it could be a separate hardware device.

[0022] A controller area network (CAN) 52 allows the VSC 50 to communicate with the transaxle 48 and a battery control mode (BCM) 54. Just as the battery 46 has the BCM 54, other devices controlled by the VSC 50 may have their own controllers. For example, an engine control unit (ECU) may communicate with the VSC 50 and may perform control functions on the engine 12. In addition, the transaxle 48 may include one or more controllers, such as a transaxle control module (TCM), configured to control specific components within the transaxle 48, such as the generator 14 and/or the motor 40.

[0023] The BCM 54 communicates with the VSC 50 via the CAN 52. The BCM 54 provides information to the VSC 50, such as the temperature, the SOC, and/or other operating conditions of the battery 46. The BCM 54 also communicates to the VSC 50 information such as a discharge power limit for the battery 46. The discharge power limit depends, in part, on the particular battery being used, and as explained below, also depends on the operating conditions of the battery. A battery manufacturer may provide battery data, including discharge power limits for various operating conditions. Typically, the discharge power limit is a power level, beyond which operation of the battery, for

some length of time, may damage the battery. Thus, it is generally desirable to keep the output power of a battery, such as the battery 46, at or below the discharge power limit. A graph illustrating the battery output power in relation to the discharge power limit is shown in Figure 2.

[0024] As shown in Figure 2, the discharge power limit is not a constant value, but rather, changes over time as the operating conditions of the battery 46 change. In particular, as the temperature of the batter 46 gets very high or very low, the discharge power limit will be reduced. In addition, as the SOC of the battery 46 decreases, the discharge power limit will also decrease. Conversely, as the temperature of the battery 46 leaves the very hot and very cold ranges, and as the SOC increases, the discharge power limit will also increase. The age of a battery, such as the battery 46, can also affect the discharge power limit. Typically, the discharge power limit will decrease as the battery gets older.

[0025] As shown in Figure 2, the battery output power changes over time based on changes in vehicle operating conditions. For example, when the driver demands a sharp increase in vehicle torque, known as "tip in", the battery output power increases so that the motor 40 and/or gen-

erator 14 can provide additional output torque to the vehicle wheels 36. The battery output power also increases as the generator 14 supplies torque to start the engine 12.

[0026] The battery output power represented by the curve in Figure 2, includes the power provided to the motor 40 and/or generator 14, and may also include power provided to other vehicle systems and/or devices. In addition, not all of the power provided to the motor 40 and/or the generator 14 is translated into torque. This is because each of the electric machines 14, 40 has electrical losses associated with its respective operation.

[0027] Figure 3 shows a flow chart 56 illustrating a method in accordance with the present invention. At the outset it is noted that although the steps in the flow chart 56 are shown according to a particular sequence, certain steps may be performed in a different sequence, and even concurrently with other steps. As shown at step 58, the discharge power limit is determined. As described above, the discharge power limit--see Figure 2--is a variable quantity, dependent on the hardware of the battery 46, as well as its operating state. At step 60, the battery output power is determined. As shown in Figure 2, the discharge

power limit and the battery power output are not merely determined one time, nor are they necessarily determined in any particular sequence. Rather, determination of the discharge power limit and the battery output power is an ongoing process. In particular, the BCM 54 monitors battery conditions and provides information to the VSC 50 at some predetermined interval.

[0028] Returning to Figure 3, it is shown that at step 62 a first output power level, or an "engine starting power level" is determined. The engine starting power level, shown in Figure 2, may be defined by a predetermined constant value, or it may be a variable value. As described more fully below, the engine starting power level is related to both the discharge power limit and an amount of output power for the battery 46 that is necessary to operate the generator 14 to provide starting torque to the engine 12. Thus, the engine starting power level can provide an indicator of when starting the engine 12--using the generator 14--will cause the battery 46 to reach the discharge power limit. If the discharge power limit is reached during an engine start, a reduction in the torque provided by the generator 14 to the vehicle wheels 36 may be required to bring the battery output power back down below the dis-

charge power limit.

[0029] Returning to Figure 3, it is shown that at decision block 64, it is determined whether the battery output power is at or above the engine starting power level. If it is not, the engine 12 is not started--see step 66. If, however, the battery output power is at or above the engine starting power level, the engine 12 is started--see step 68. Step 68 is illustrated in Figure 2 at the point that the battery output power curve contacts the engine starting power level curve.

[0030] As discussed above, determination of the engine starting power level can be made in a number of different ways. For example, in the embodiment shown in Figure 2, the engine starting power level is defined by a constant offset, or constant distance (d), from the discharge power limit. Although the distance (d) can be set to any convenient level, it should be large enough so that the battery 46 can supply power to start the engine 12 without reaching the discharge power limit. If the battery output power reaches the discharge power limit as the engine 12 is starting, it may be necessary to reduce the torque provided to the vehicle wheels to reduce the battery output power. As discussed above, this condition is undesirable, as it leads to

a non-transparent engine start. Conversely, it is desirable that the distance (d) is not made too large, otherwise the engine 12 may be started too frequently, thereby reducing some of the benefit of operating an HEV.

[0031] One method of determining a constant offset--i.e., the distance (d) in Figure 2--is by operating a vehicle, such as the vehicle 10, under a variety of different conditions, starting the engine under each of these conditions, and measuring the output power of the battery required for engine start. Figure 4 shows a graph illustrating two curves: engine speed and battery output power. At the point where driver demand increases (tip in), a controller, such as the VSC 50, commands an engine start, and the battery output power begins to increase. The battery output power increases until the engine begins to output torque, at which point the battery output power decreases.

[0032] The distance between the battery output power prior to tip in, and the peak battery output power, is shown in Figure 4 as distance (c). The graph shown in Figure 4 represents an engine start under one set of operating conditions. Other values for the distance (c) can be determined while the vehicle is operating under a variety of other

conditions. For example, the vehicle may be operated at different temperatures, at different altitudes, and with engines having been operated for a different number of hours or over a different number of miles. The values of the distance (c) can then be mathematically combined, for example, by using some statistical technique. In this way, an appropriate offset can be determined, and used as a constant value to determine the engine starting power level. Thus, the offset may be considered a starting power value, which can be programmed into a controller, such as the VSC 50. The VSC 50 can then define the engine starting power level as a difference between the discharge power limit and the offset.

[0033] Another way to determine the engine starting power level is to use a variable offset which can be determined by the VSC 50 by implementing a function that uses inputs based on different vehicle operating conditions. For example, Figure 5 schematically illustrates a function that can be used to determine a variable offset to define the engine starting power level. Initially, a calibratable value (CAL) is defined and programmed into a controller, such as the VSC 50. The calibratable constant (CAL) may represent a nominal amount of battery output power required to start

an engine, such as the engine 12. The constant (CAL) is then modified by a factor that considers the altitude at which the vehicle 10 is operating. Because it takes less torque to start an engine at higher altitudes, the altitude factor shown in Figure 5 decreases as the altitude of the vehicle 10 increases. Thus, there is an inverse relationship between the altitude factor shown in Figure 5 and the altitude of the vehicle 10. Similarly, there is an inverse relationship between the temperature factor and the temperature of the coolant water of the engine 12. That is, as the coolant temperature decreases, more torque is required to start the engine 12, and therefore, the temperature factor increases. Finally, electrical losses of the generator 14 and/or motor 40 are added in so that the VSC 50 can determine the engine starting power level.

[0034] When a variable function, such as the function illustrated in Figure 5, is used to determine the engine starting power level, the offset--i.e., the distance (d) shown in Figure 2--will be closer to, or farther away from, the discharge power limit depending on the vehicle operating conditions. Of course, a function, such as the function illustrated in Figure 5, may include other factors to determine the engine starting power level, or alternatively, may

include fewer factors, or different factors, than the ones shown in Figure 5. When using the function, such as the function illustrated in Figure 5, the various factors used in implementing the function may be static input values pre-programmed into the VSC 50, or they may be dynamic values. For example, the altitude factor may be determined from a look-up table preprogrammed into the VSC 50, that relates vehicle altitudes to engine starting torque. This look-up table could be programmed into the VSC 50 one time, and relied upon throughout the life of the vehicle 10.

[0035] Alternatively, the VSC 50 may employ the use of an adaptive algorithm that replaces values within the look-up table based on actual operating conditions of the vehicle 10. In such a case, the input values used by the function illustrated in Figure 5, would be dynamic values that would be updated according to the actual operating conditions and measurements taken while the vehicle 10 is operating. The same is true for the other inputs, such as the temperature factor and the electrical losses. In either case, use of a function, such as the function illustrated in Figure 5, would result in a variable engine starting power level. In the case of using static inputs, the engine starting power

level would be determined based on preprogrammed relationships; whereas, using dynamic input values allows the relationships to be updated and tailored to the specific vehicle being operated.

[0036] While the best mode for carrying out the invention has been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.